# A Study of SSI Effects Incorporating Seismic Wave Incoherence within the DOE Complex

2014 U.S. DOE Natural Phenomena Hazards Meeting

Carl J. Costantino and Associates

*www.cjcassoc.com*

COSTANTINO & ASSOCIATES

# Introduction

- CJC&A was commissioned to evaluate the effects of seismic wave incoherency on the SSI response at a DOE complex in the eastern US.
- The site is characterized as a relatively stiff rock site with high frequency input motions.
  - Input motions peak near 30 Hz.
  - Structure has a large spatial area (160,000 sq. ft.)
  - Site/structure is an excellent candidate for reduction of high frequency motions due to spatial variation of ground motions.

# Background

- Seismic wave incoherence is the spatial variation of the amplitude and phasing of seismic ground motions over an extended area.
- In terms of its impact on SSI, incoherence generally tends to reduce foundation motions relative to the free field input motion.
  - Generally, if the foundation is relatively large and stiff, results in reduced seismic demands within the structure.
  - The amplitude of foundation motions generally decrease as the frequency of the motion increases.
- Incorporation of incoherency in SSI has been implemented within the nuclear power industry and is accepted by regulators.
- Incorporation of incoherency in SSI within the DOE complex has NOT yet been implemented to date.

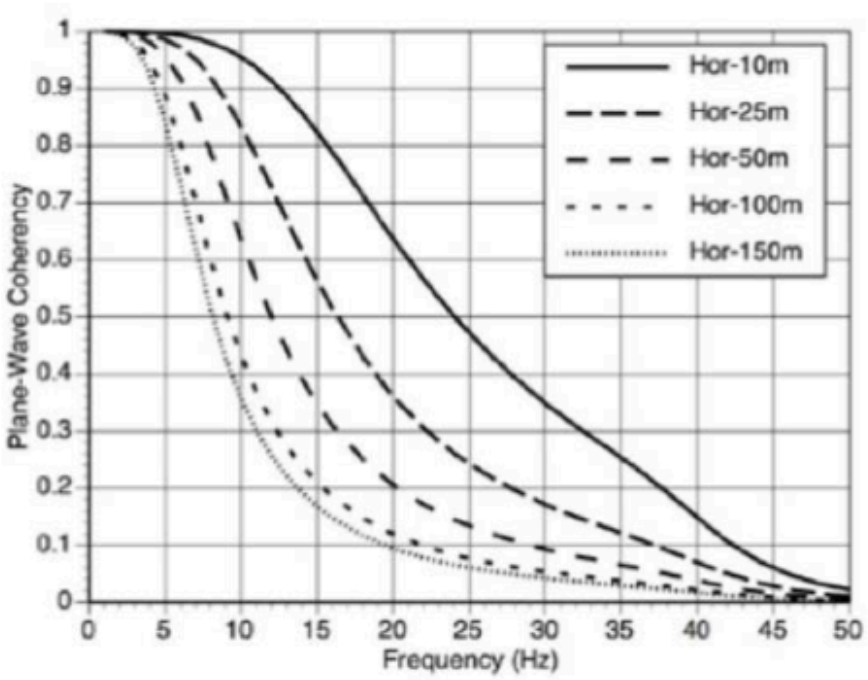
# Incoherency Implementation

- EPRI has performed validation of the implementation of the U.S. NRC approved methodologies for considering seismic wave incoherence in CLASSI and SASSI.
  - EPRI report 1015111, "Program on Technology Innovation: Validation of CLASSI and SASSI Codes to Treat Seismic Wave Incoherence in Soil-Structure Interaction (SSI) Analysis of Nuclear Power Plant Structures."
- This study uses the SASSI-SRSS methodology implemented in SASSI2010.
  - Decomposes the coherency matrix into spatial modes.
  - Transfer functions are modified for each spatial mode and combined by the SRSS method.

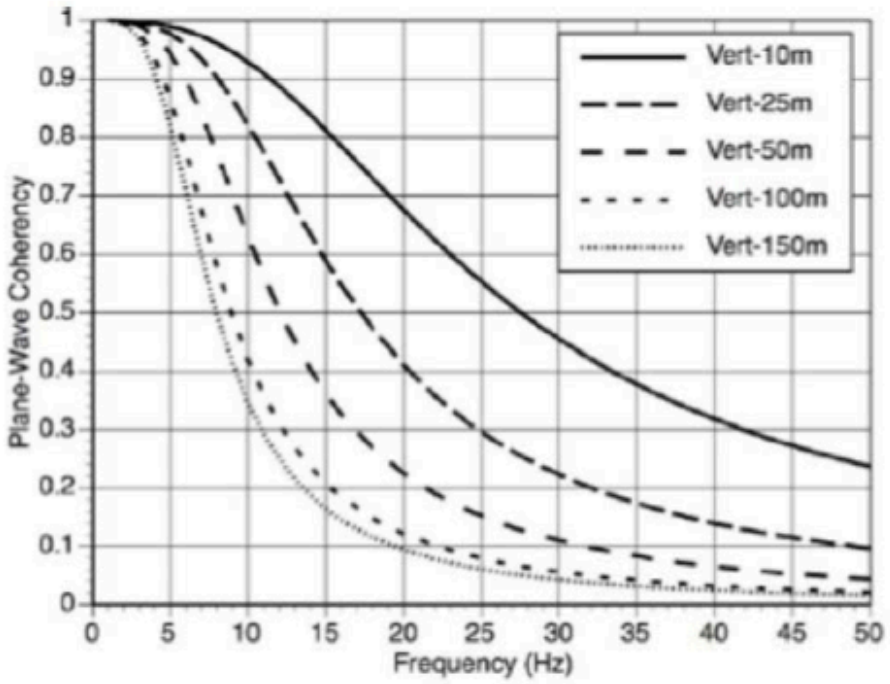
# Incoherency Implementation (2)

- The Abrahamson rock coherency function was used for this study.
- This rock coherency model is accepted by the NRC for both rock and soil sites.

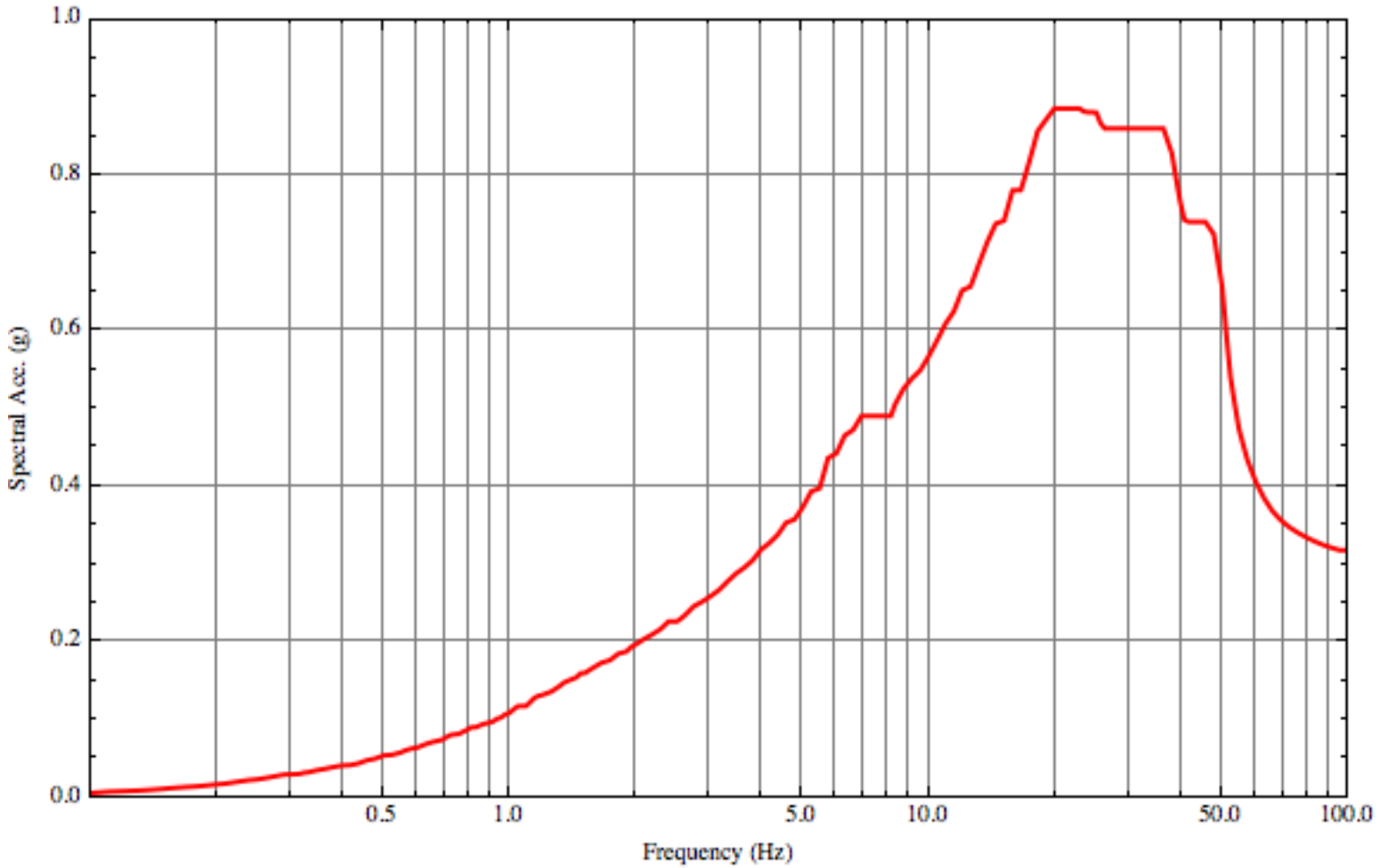
**Horizontal Coherency**




**Vertical Coherency**



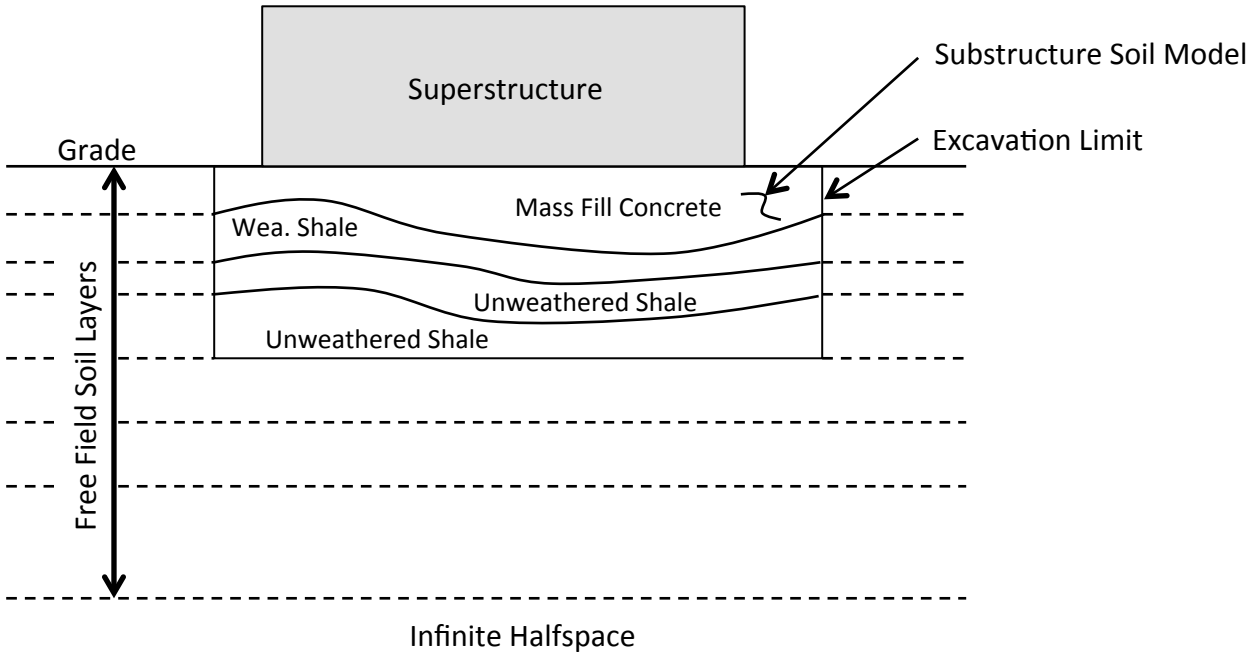
# Surface Input Design Spectrum at the Site



# Description of the SSI Problem

- The SSI problem is characterized by the following:
  - Large footprint, squat shear wall structure
  - Soil profile is based on excavation of residuum and "soft" weathered shale at the site, and replaced with mass concrete fill from the top of shale to the grade level.
  - Mass concrete is founded on layers of weathered and unweathered shale (3000 fps < $V_s$ < 6000 fps)
- The original SSI model incorporates the mass concrete fill substructure.

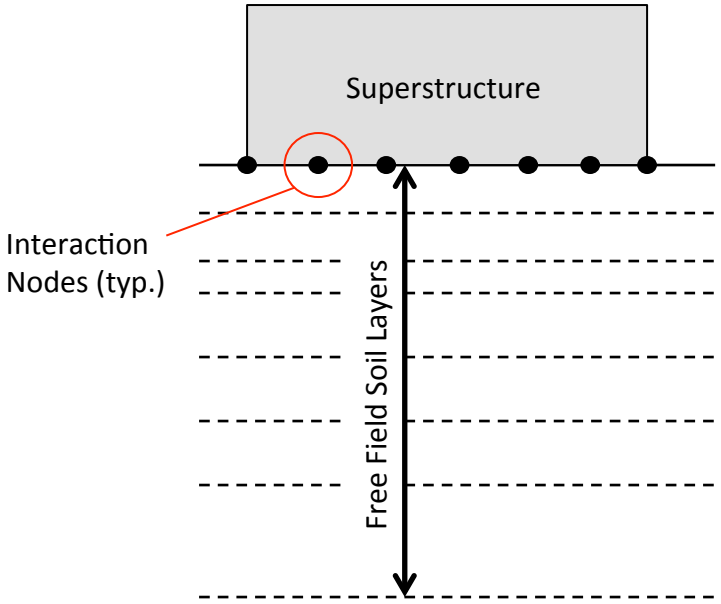
# Schematic of the Original Coherent SSI Model used for Design



# Incoherency Analysis Models

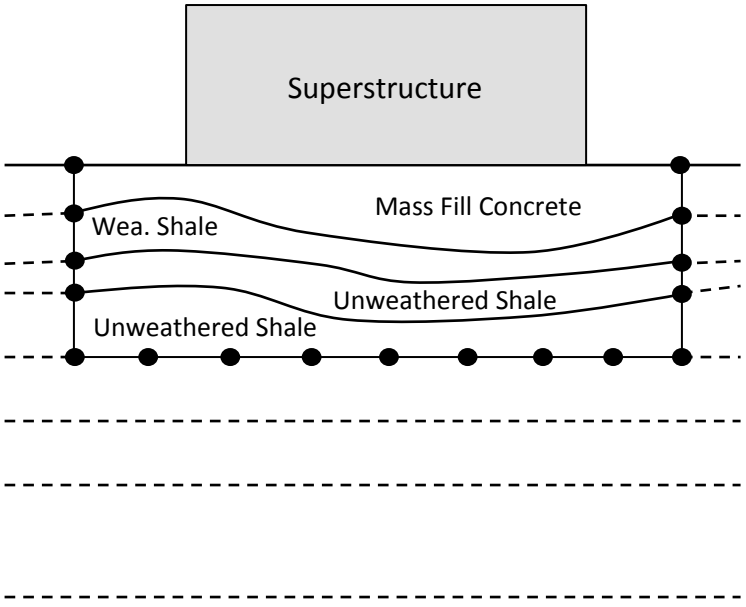
**Superstructure Founded on a Layered Halfspace**

- This is the typical implementation for incorporation of incoherency into SSI.
- Interaction nodes are at the surface.




**Superstructure Founded on Embedded Substructure**

- This is an embedded SSI model.
- Interaction nodes are at the sides and bottom of excavation.



# Incoherency Analysis Models (2)

- A simplified FE model of the facility was generated.
- The FE model has the following characteristics:
  - Same dominant natural frequencies of the target facility.
  - Seismic mass and building footprint were consistent with the target facility.
  - Localized slab/roof properties around the structure were varied to produce a broad frequency range of response around the structure.

# Incoherency Analysis Parameters

- As previously shown, coherent and incoherent SSI analyses were performed on the surface and embedded FE models.
- A single deterministic SSI analysis is performed on each using the BE soil profile for the site.
- Other sensitivity studies were performed which are not all covered here:
  - Number of spatial modes required.
  - Effect of basemat stiffness.
  - Rocking and torsion response.
  - Other building specific features.

# Observations from the Surface Founded Model (Superstructure on a Halfspace)

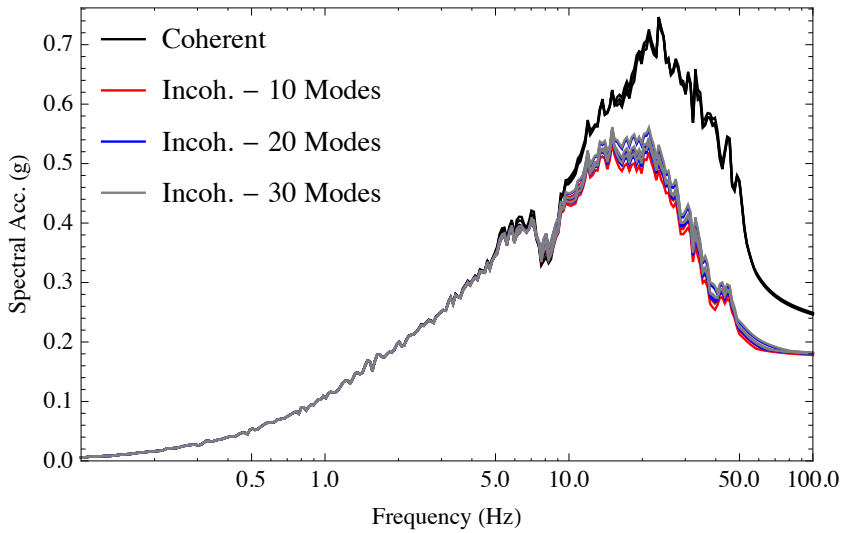
- The results are consistent with industry experience and expectations.
- The large footprint and high frequency input results in reductions in ISRS of up to 40% (system dependent).
  - ZPA reduces up to 30%.
- No surprises or unusual behaviors were observed.
- Additional rocking and torsional responses were observed, but were very low magnitude.
  - This structure is highly symmetric.

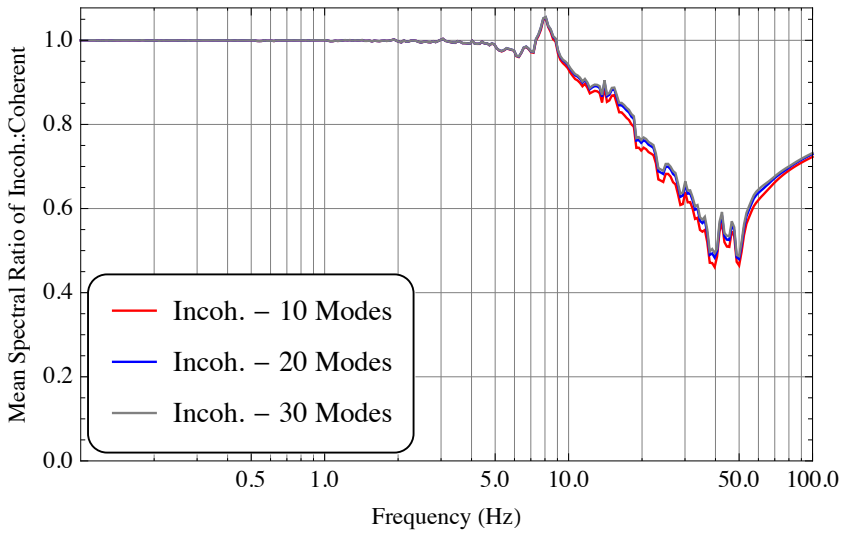
# Typical Basemat Level ISRS – Surface Founded Structure

## 5% Damped ISRS

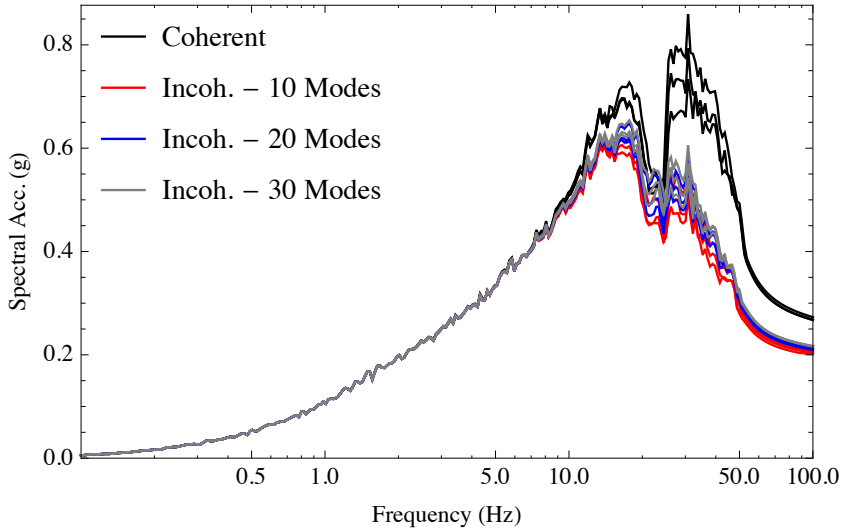
## Mean Spectral Ratio

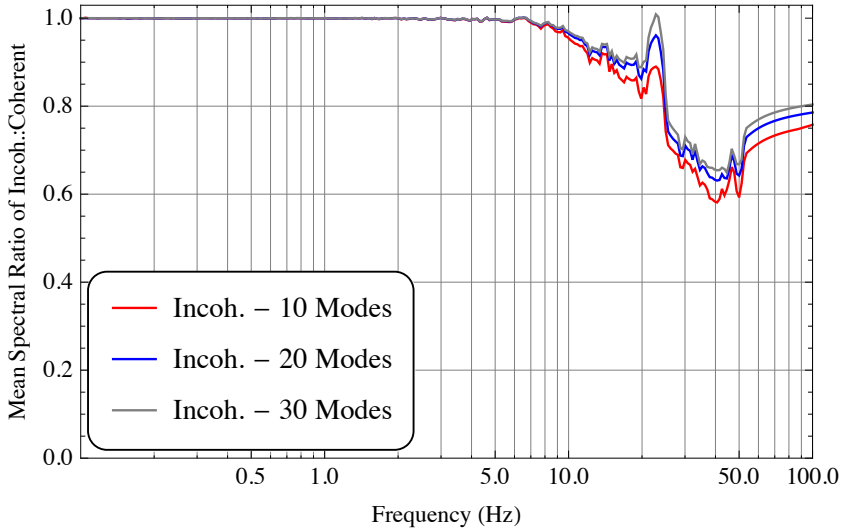
Horizontal




Vertical



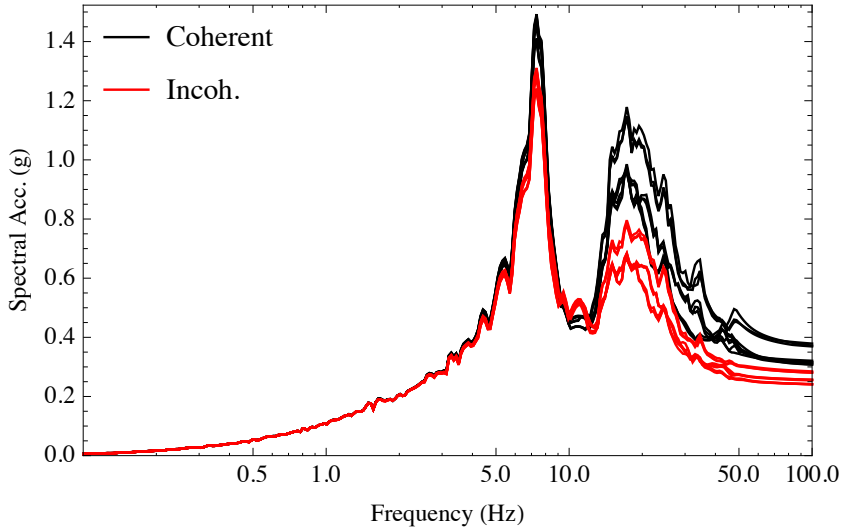



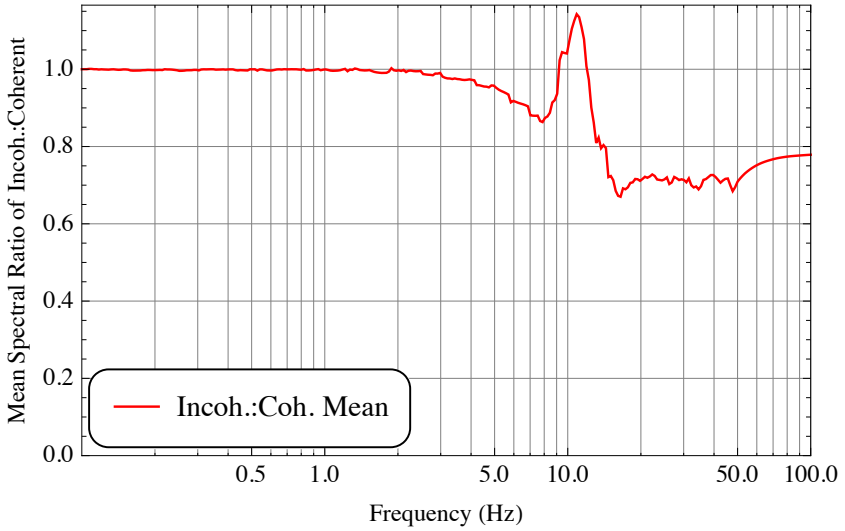
# Typical ISRS at Intermediate Floor – Surface Founded Structure

## 5% Damped ISRS

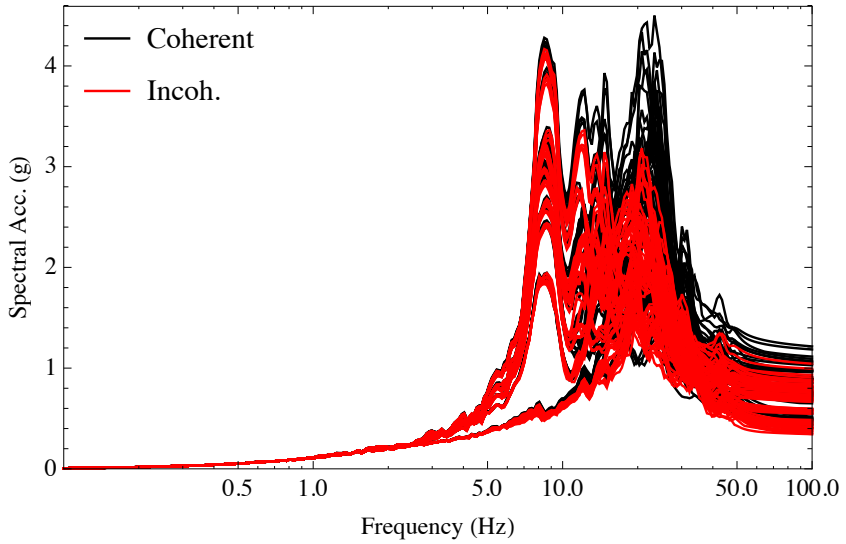
## Mean Spectral Ratio

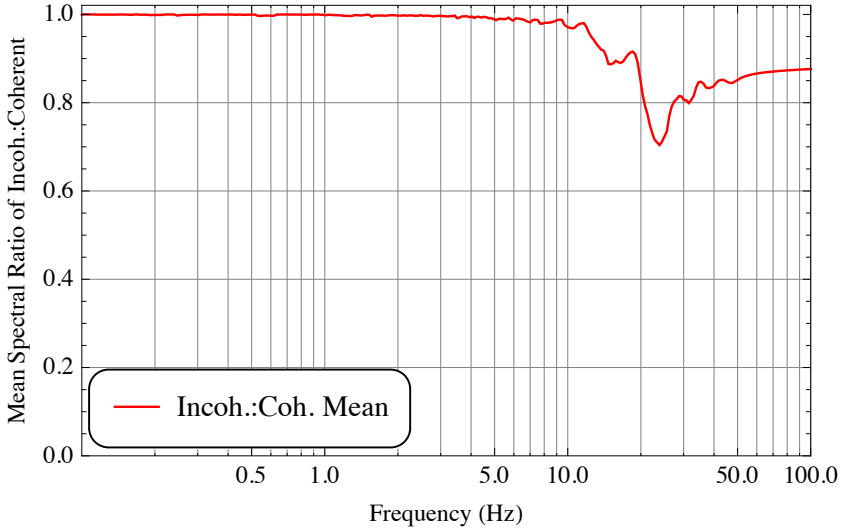
Horizontal



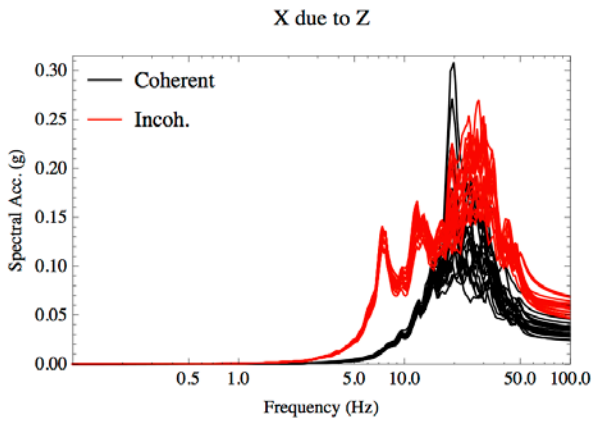



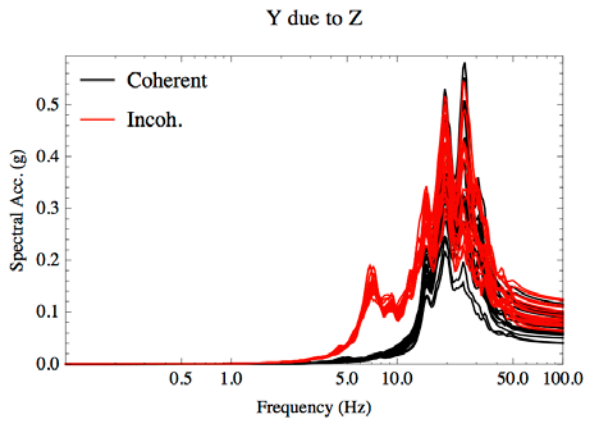

Vertical

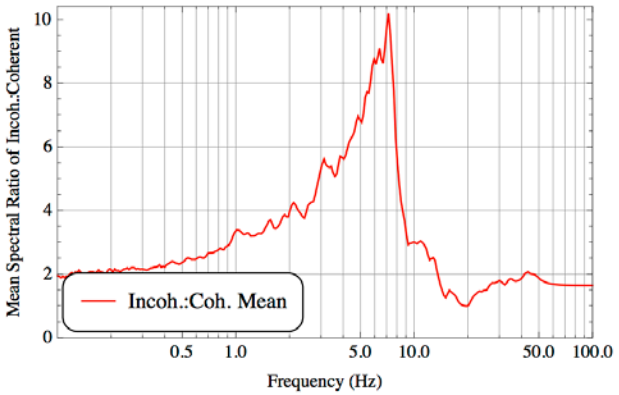


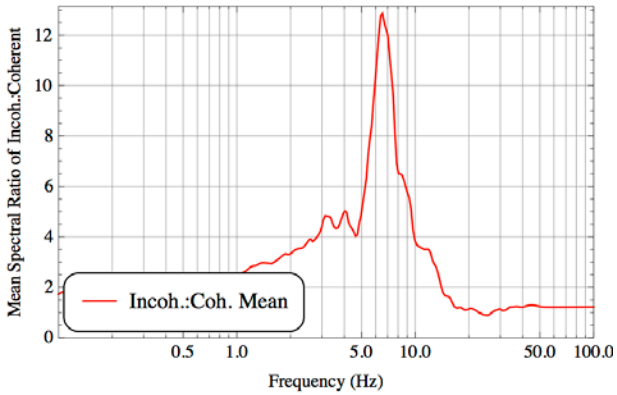



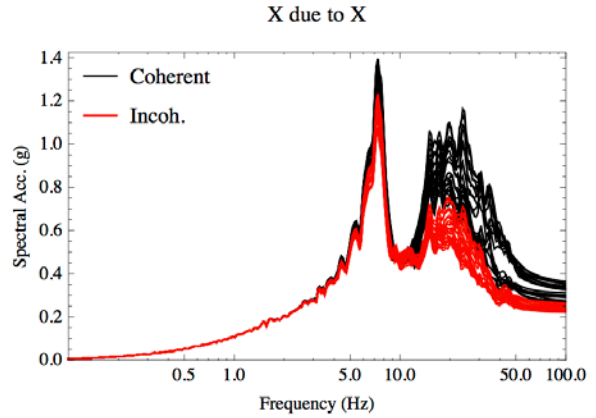
## Example Results for Rocking and Torsion Responses

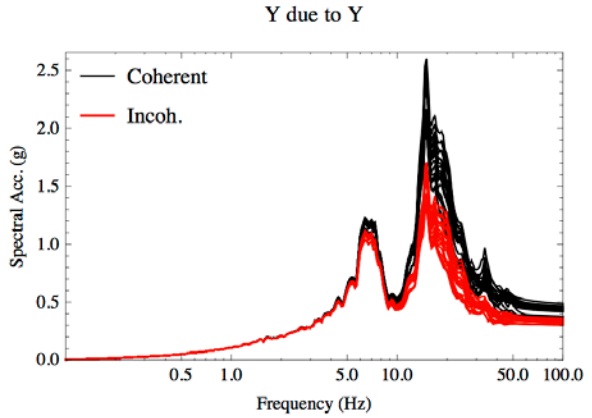


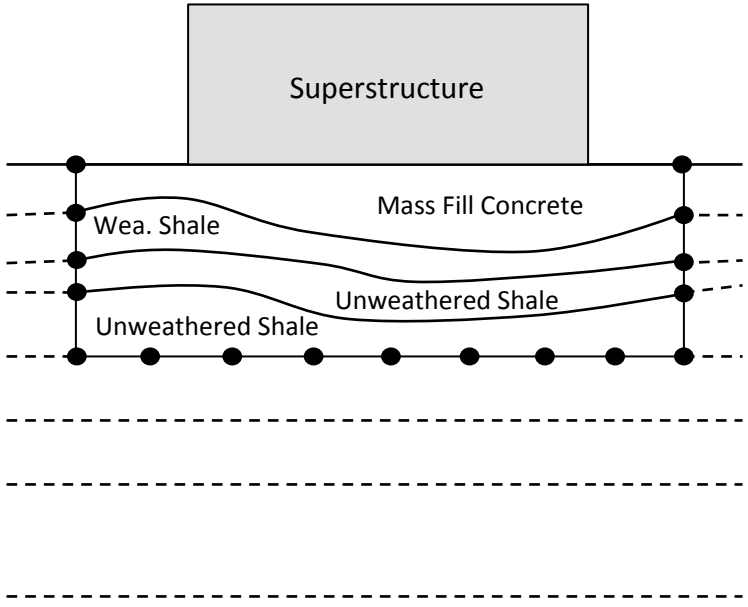



# Observations from the Embedded Model (Superstructure on a Substructure)

- In addition to the surface founded case (typical implementation), the embedded substructure model was analyzed.
- The purpose was to investigate the impact of embedment effects on incoherent response relative to the surface model.
- In general, high frequency ISRS amplitude reduce up to ~30%.
- However, at several locations on the basemat there are points of increased ISRS relative to the coherent analysis.

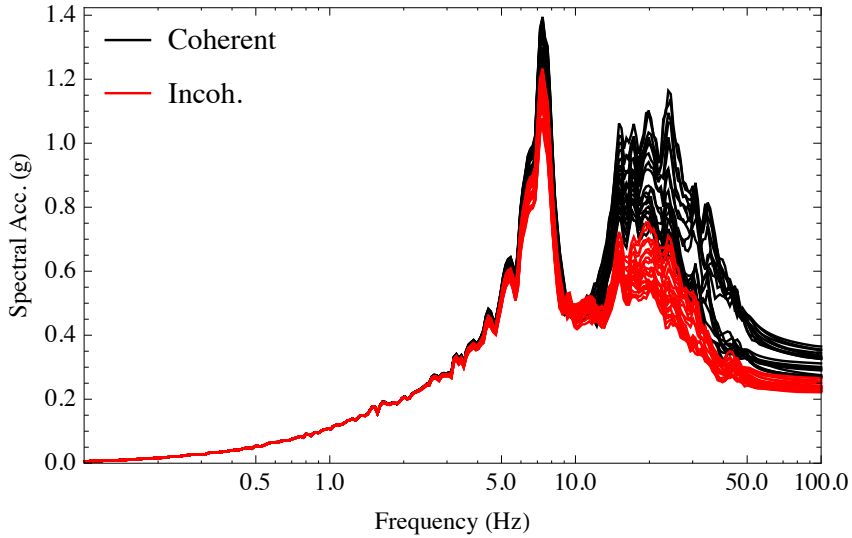


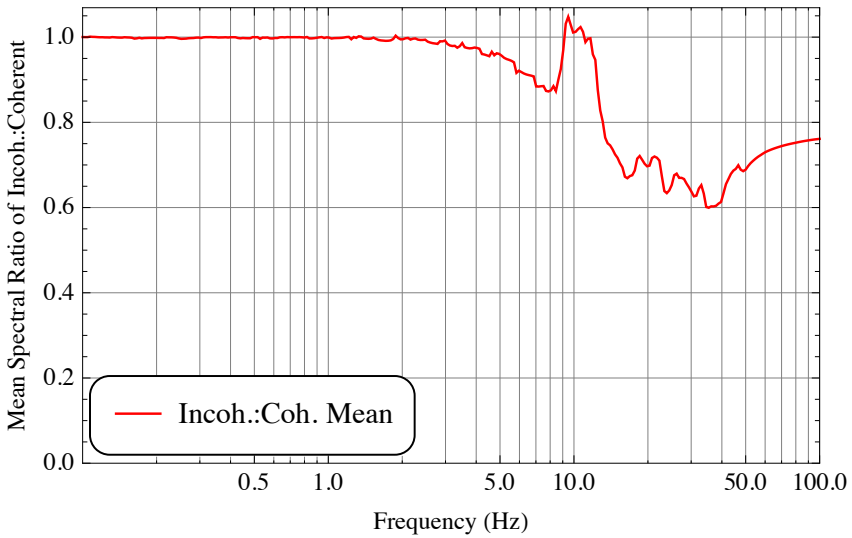
# Typical ISRS at Intermediate Floor – Surface Founded Structure (X Direction)

## 5% Damped ISRS

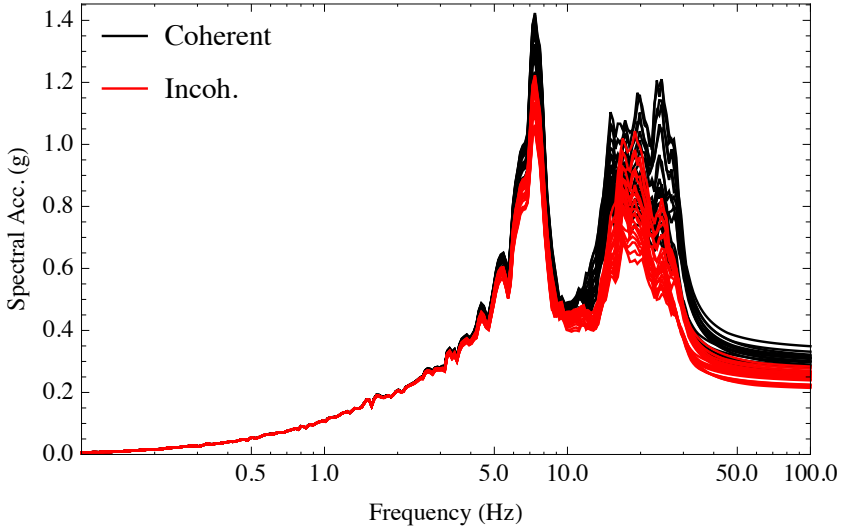
## Mean Spectral Ratio

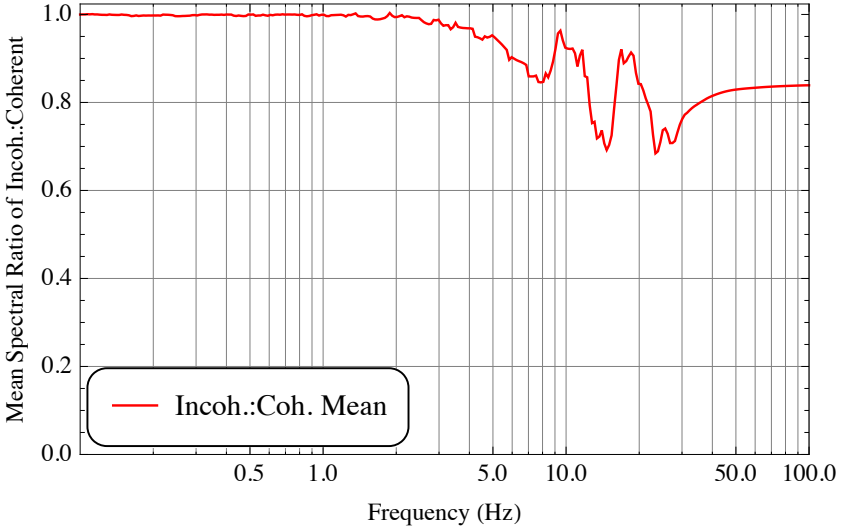
Surface Structure




Embedded Model



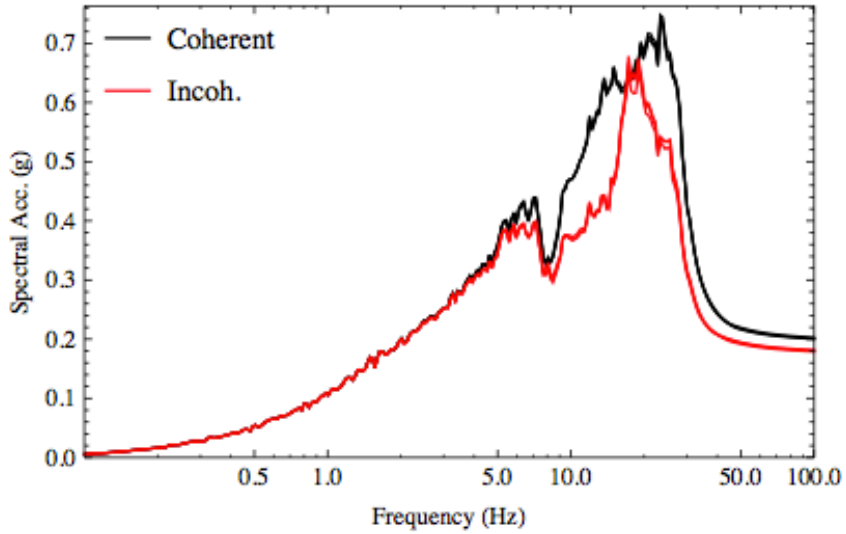



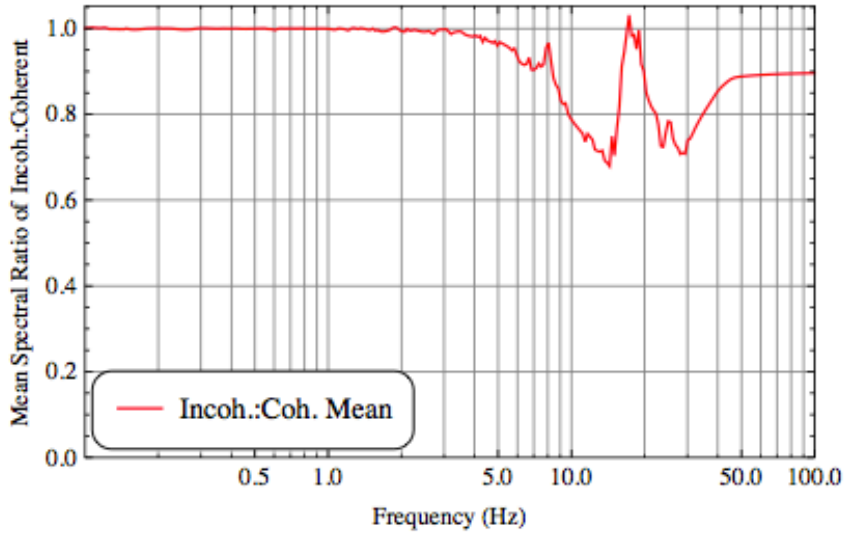
## Basemat ISRS – Basemat Level

5% Damped ISRS

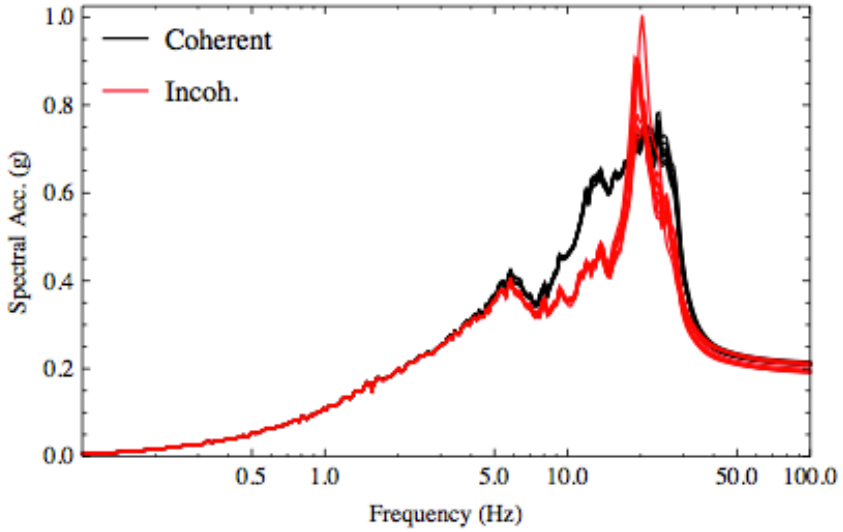
Mean Spectral Ratio

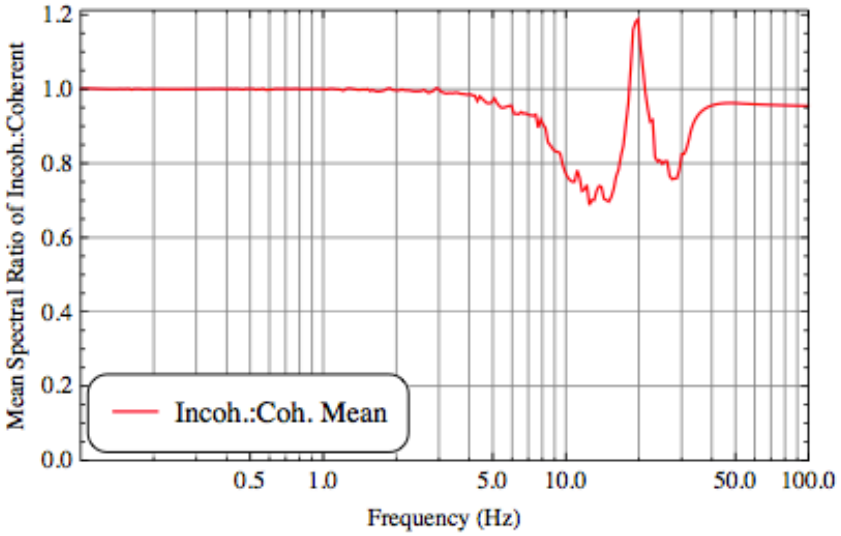
X Direction




Y Direction



# Overall Observation

- This large footprint structure on a stiff site is an excellent candidate for the application of seismic wave incoherency.
- High frequency ISRS reductions are observed, consistent with industry experience.
- The method of modeling the SSI problem can impact the results:
  - The standard surface implementation of incoherence behaves consistent with expectations.
  - The application to an embedded problem can introduce artifacts in the response not observed in the surface case.